NASA-CR-202721

FINAL REPORT NCA2-757, "Studies of MESUR Aeroshell Configuration in Hypersonic Rarefied Flows of CO2".

1. Summary

1a. Introduction

The subject research was undertaken by faculty of the Department of Mechanical Engineering, University of California at Berkeley, under the a NASA-AMES, University Consortium Agreement, NCA2-757. The work was to provide collataral data, supplementing but not duplicating the work of a much larger effort conducted under joint NASA and AGARD sponsorship. This latter work, which is now well documented in many internal and external publications, was conducted at various European laboratories and supplemented through calculation and other work in the United States. The work of the present report was not funded through NASA/AGARD, although study of the MESUR Aeroshell was common to the two programs.

The MESUR Aeroshell is a standardized sphere-nose, 70 deg. half-angle cone with specified ratios of cone diameter to nose and edge radii. This shape is expected to be of importance for research satellites and for Mars explorations and landings. Work of the consortium at Berkeley would, as elsewhere, examine flow fields and aerodynamic forces on the standard shape. However, since all other work involved the use of nitrogen or argon or helium, it was proposed that the studies at Berkeley would focus on the use of carbon dioxide as the primary test gas. This seemed a particularly interesting decision since CO2 is one of the principle atmospheric constituents both for Mars and for Venus. It was proposed that testing would be done within the Berkeley Rarefied Gas Wind Tunnel using the electron beam system to measure flowfield density and that a torsion balance would be constructed to measure lift and drag. Hypersonic flows would be produced by free jet expansion from the exit orifice of a heated ceramic tube.

1b. Personnel.

Two graduate students of mechanical engineering who were seeking projects leading to degrees in engineering at the Masters level were engaged as Graduate Assistants. The first of these, Mr. Javier Barraza, became supported in part through a NASA Minorities in Graduate Study Fellowship which was awarded in the spring of 1993 and continued until the spring of 1995. Mr. Barraza was assigned responsibility for the electron beam studies.

Mr. Gabriel Millos, the second of the two Graduate Assistants, was supported through a two-year Cota-Robles Fellowship, awarded in July 1993. The second portion of the work, that of the construction and use of the torsion balance, was assigned to Mr. Millos. Both persons were also involved in alterations and renewal of the tunnel in preparation for the work to come.

The University and NASA were very fortunate to obtain these two fine persons as Graduate Assistants. Both worked with diligence and effectiveness and each developed significant information. Both were awarded degrees at the Master's level as of December, 1995.

1c. Funding

The original grant of $40,000.00 served through the initial period of the Consortium Agreement and through three additional extensions without additional funding. Expenditures were limited to the purchase of supplies, replacement components, hourly pay for electronic or mechanical technicians and for other miscellaneous expenses.

2. Research activities and results.

2a. A detailed report by Javier Barraza was submitted in partial satisfaction of the Master of Engineering Degree under the terms of Plan 2. A copy of this report, which is a major element of this final report, contains a detailed account of the several portions of Mr. Barraza's work. These are listed as follows: Development and calibration of a CO2 flow metering and control system, Installation and trial of a LN cooled cryogenic pump to increase the mass flow of CO2, Restoration and calibration of the monochrometer and detector system. This activity included the installation of new collection optics. Testing of the complete system in efforts to identify suitable CO2 fluorescent lines and to obtain intensity calibrations as a function of the local density of CO2. Modification of the vacuum buffer which lies between the exit orifice of the electron beam assembly and the high vacuum beam gun. This modification was needed to reduce the diffusion of CO2 from the test section along the beam path back to the electron emitter. Continuing repairs were required to curtail breakdown of the insulation on the high voltage leads within the electron gun.

As it ultimately developed, it was impossible to meet the objectives of the study. The primary obstacle was found to be the low frequency noise arising from the interaction of CO2 with the heated beam filament. Repeated trials using Nitrogen, then CO2, produced similar results. With Nitrogen flows steady fluorescent lines would be seen, very much as in the many previous studies using this equipment. The Nitrogen flow would then be stopped and a small flow of CO2 would be introduced. Within a very short time low frequency noise of the fluorescent signal would be observed, with the effect that the spectra from scan to scan could not be correlated.

Only a few studies of electron beam fluorescence in CO2 have been made. These were conducted in static systems in which the electron beam source was well isolated by a high vacuum buffer chamber. Modifications of our system were considered, but none could be implemented within the constraints of time and available funding. A well controlled examination of the production of electron emission noise in the presence of CO2 and other potentially reactive gases would prove of practical value and would also provide an avenue towards new fundamental information.

2b. A detailed report "Flat plate and MESUR Aeroshell Drag Measurement in Rarefied Gas Flows of Nitrogen and Carbon Dioxide" was submitted by Gabriel Millos in partial satisfaction of the University requirements under Plan 2. for the Degree of Master of Engineering Science. Mr. Millos designed a general purpose torsion balance, contributed to its construction, and, following some period of calibration and initial testing, measured the aerodynamic drag on aluminum flat plates and on the MESUR Aeroshell, also of aluminum. The angle of attack was varied in these tests, and both N2 and CO2 were use as test gases. Density and Mach Number were calculated at the model mid-point. In these measurements the flow Mach number was 14.5 for N2 and 10.3 for CO2. The Knudsen numbers ranged from 0.057 to 0.300. Background and results are reported in full in Millos' report which constitutes the second major element of this final report.

The reader will note that Drag Coefficients for the flat plate in Fig. 5 would appear to show substantial errors of measurement, although the second run with CO2 (solid triangles) may well be correct. The work represented in Figs. 6 through 12 should be accepted as giving trends and magnitudes correctly. Unfortunately an overall uncertainty analysis was not performed. Mr. Millos worked with great care and intelligence in all areas and measured the sensibility of the balance system carefully. He also provides a thorough discussion of the determination of flow characteristics. The small size of the free jet expansion resulted in undesirable flow divergence and, relative to the axial length of the model at angle of attack, a rapid change in flow properties along the axis. Occasional instabilities possibly related to this shortcoming are discussed in the report.

Drag coefficients over all values of the Knudsen Number and at all angles of attack were found to be smaller for CO2 than for N2. In all cases using CO2, values of the drag coefficient rose from values of 2.00 or below in near continuum flows, to values of 3.00 or larger at the largest Knudsen Numbers. In several tests using N2 the trends of Drag coefficient were found to be similar although the values of CD for near continuum flows would be larger and the slope to the larger Knudsen Numbers would be smaller. In a few cases values of CD for N2 remained constant at about 3.00 or larger over the range of Knudsen Number. These inconsistencies could not be rationalized within the time available to Mr. Millos.

Values of CD determined for the Aeroshell are shown in Figures 9. through 12. The behavior is very similar to that for the flat plate but the values at all Knudsen Numbers are slightly smaller. The Aeroshell at 90 Deg. may be compared to the flat plate at 70 Deg. Results for CO2 for the Aeroshell indicate values of CD rising from about 1.75 to about 3., while those for the flat plate at 70 Deg. rise from a value just below 2. to a value just above 3.

3. Summary

The work conducted by two Masters Degree candidates under Consortium Agreement NCA2-757 is described in the foregoing paragraphs. Both students, Mr. Javier Barraza and Mr. Gabriel Millos, were awarded Masters Degrees as of December, 1995. In both cases the work has provided useful but preliminary information relating to the conduct of studies of the MESUR Aeroshell in rarefied gas flows of CO2 and N2.

The work was conducted under the supervision of Professor F.C. Hurlbut, Principal Investigator, and Professors M. Holt and V. Carey, 2nd and 3rd Principal Investigators in collaboration with Dr. John Cavolowsky of NASA Ames Research Center.

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